Advanced Monolithic X-Band GaAs MMIC Receiver - Design and Reliability Issues in Medium Scale Integration

Narayan R. Mysoor
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Wendell C. Peterson, Daniel P. Siu, and Daniel R. Ch'en
Microwave Monolithics Inc.
Simi Valley, CA 93065

NASA GaAs MMIC Reliability and Space Qualification Workshop
NASA Lewis Research Center, Cleveland, Ohio
August 31- September 1, 1993

ACKNOWLEDGMENTS: The research described in this paper was performed by Microwave Monolithic Inc., under the direction of Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration Small Business Innovation Research (NASA SBIR) program.

OUTLINE

- o Objectives
- o Advanced deep space spacecraft transponder
- o Advanced MMIC GaAs X-band receiver chip
- o Performance of MMIC chips from the first iteration
- o Summary

Advanced Transponder Development Objectives

- o Develop and evaluate MMIC technology for advanced X-band and Ka-band transponders to reduce demand on spacecraft resources:
  - Mass
  - Volume
  - Power
- o Improve reliability
- o Reduce flight hardware costs

ADVANCED DEEP SPACE SPACECRAFT TRANSPONDERS

JPL

Telecommunication Transponders for deep space spacecraft applications provide independent uplink command and turn around ranging functions, as well as do wnlink telemetry and radiometric capabilities

FUNCTIONS

- **Precision phase/frequency reference transfer from the uplink signal**

- **Demodulation of the command and ranging signals from the uplink carrier**

- **Generation of a coherent or non-coherent downlink tracking signal for the earth based Deep Space Network .**

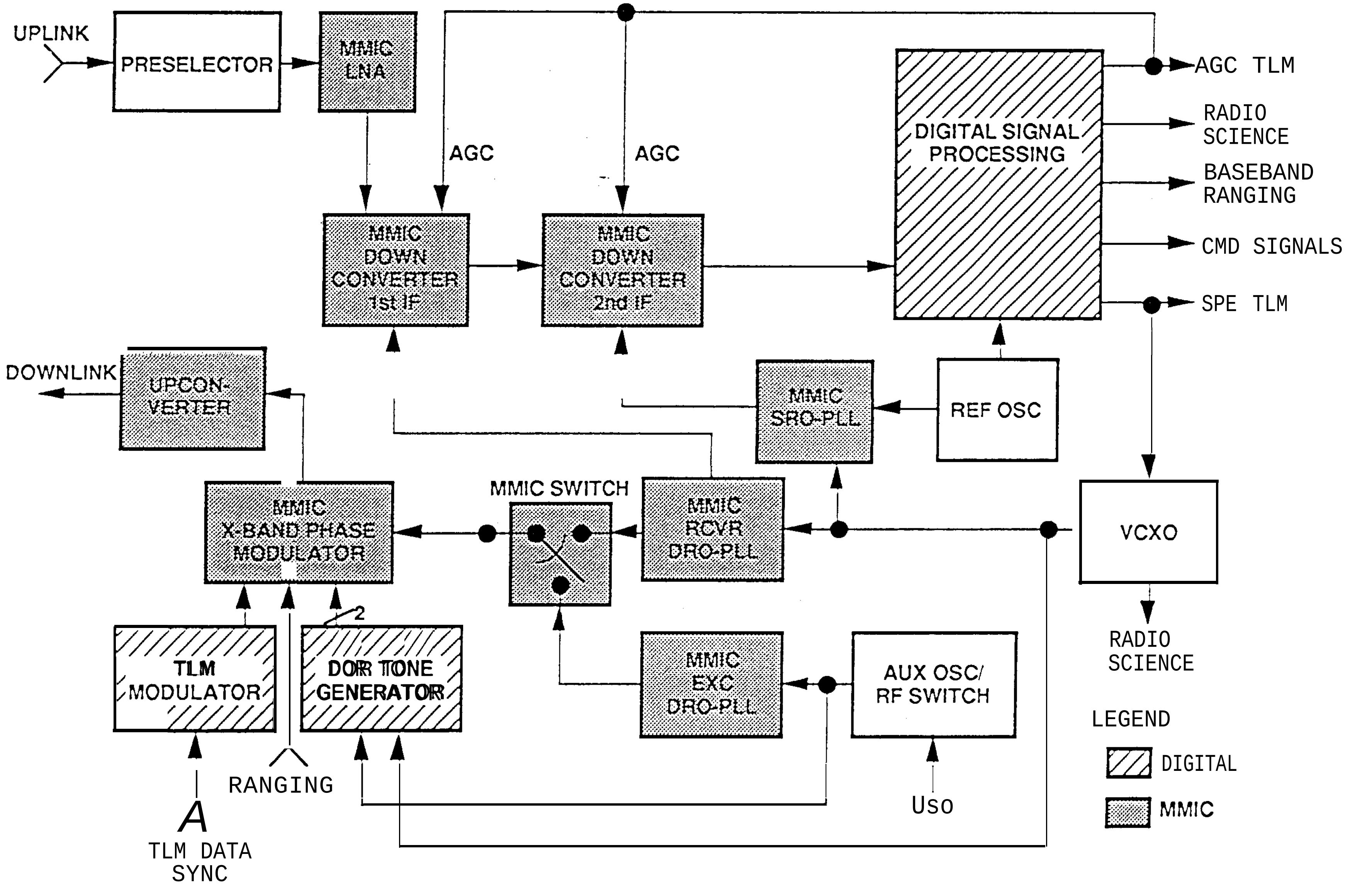
- **Provide downlink signal modulation with composite telemetry data and turn around ranging or differential one-way ranging signals**

- **Provide a functional capability to utilize an external ultra stable oscillator to generate the downlink signal**

- **Provide reference signals for radio science experiments**

ADVANCED DEEP SPACE SPACECRAFT X-BAND TRANSPONDER

JPL



ADVANTAGES OF MONOLITHIC MICROWAVE INTEGRATED CIRCUIT (MMIC)

* ALL COMPONENTS INTEGRATED ON "CHIP"

* NO / LOW INTERCONNECTS

* MMIC OFFERS:
  - SMALL SIZE
  - LIGHT WEIGHT
  - HIGH RELIABILITY

ION IMPLANTED MONOLITHIC MICROWAVE INTEGRATED CIRCUIT PROCESS

* HIGH REPEATABILITY

* EXCELLENT UNIFORMITY

* LOW COST IN VOLUME PRODUCTION

HIGH RELIABILITY DESIGN

- Judicious design, ion implanted GaAs materials in conjunction with refractory metal gate process to form the MESFET active devices are used
  - Increased "yield-to-performance"
  - Excellent stability at elevated temperatures
  - Improved overall reliability

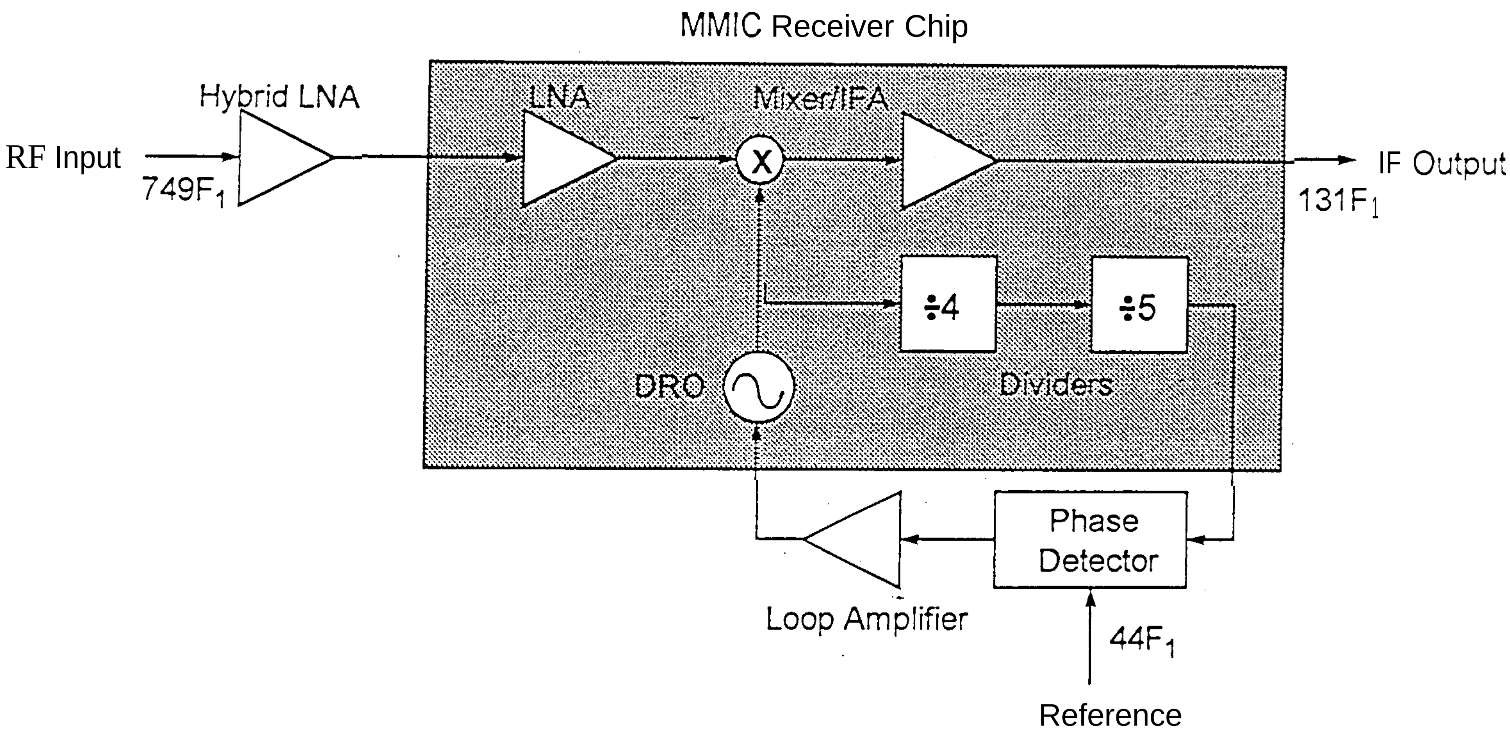
- Reduced DC and RF stress on active and passive circuits
  - Longer MTBF

- Die attached to thermal expansion matched material
  - Reduced thermal cycling stress

- Hermetically sealed package
  - Controlled, moisture free environment

- Compatibility with eventual higher level integration
  - Minimal number of interconnects

Advanced **Monolithic** GaAs X-Band Receiver Chip



Projected Chip Size ≤ 20 mm^2

MMIC CHIP SIZE SUMMARY

LNA / GAIN BLOCK	2.0 X 1.25 MM
MIXER	2.0 X 1.25 MM
IF AMPLIFIER	2.0 X 1.0 MM
VDSO	1.4 XO.9 MM
POWER SPLITTER	0.5 XO.63 MM
DIVIDE BY FOUR	2.0 x 1.5 MM
DIVIDE BY FIVE	4.2 X 2.0 MM

1) RF Amplifier (Monolithic)

PARAMETER	GOAL	PREDICTED
FREQUENCY	7.1 - 7.3 GHz	6.5 -7.8GHz
GAIN	20 dB	20 dB
NOISE FIGURE	3 dB	2.9 dB
INPUT VSWR	2:1	1.5:1
OUTPUT VSWR	2:1	1.5:1
IMAGE REJECTION		-30 dBc
P(1 dB)		7 dBm
POWER CONSUMPTION		100 mW
CHIP SIZE		1.9 x 1.25 mm

2) MIXER (Monolithic)

PARAMETER	GOAL	PREDICTED
RF FREQUENCY	7.1 - 7.3 GHz	7.0 - 7.5 GHz
LO FREQUENCY	8.353 -8.553 GHz	8.1 -8.7 GHz
IF FREQUENCY	1.253 GHz	1.253 GHz
LO POWER LEVEL		10 dBm
CONVERSION LOSS		10 dB
POWER CONSUMPTION		400 mW
CHIP SIZE		1.9 x 1.0 mm

3) VOLTAGE CONTROLLED DIELECTRIC STABILIZED OSCILLATOR (Monolithic)

PARAMETER	GOAL	PREDICTED
FREQUENCY BAND	8.353 - 8.553 GHz	TBD
OUTPUT POWER	10 dBm	11 dBm
POWER CONSUMPTION		300 mW
CHIP SIZE		1.3 x 0.875 mm

4) IF AMPLIFIER (Monolithic)

PARAMETER	GOAL	PREDICTED
FREQUENCY	1.253 GHz	1.15 - 1.35 GHz
GAIN	25 dB	25 dB
NOISE FIGURE	7.5 dB	7.3 dB
INPUT VSWR	2:1	1.5:1
OUTPUT VSWR	2:1	1.5:1
P(I dB)		7 dBm
POWER CONSUMPTION		100 mW
CHIP SIZE		1.9 x 1.0 mm

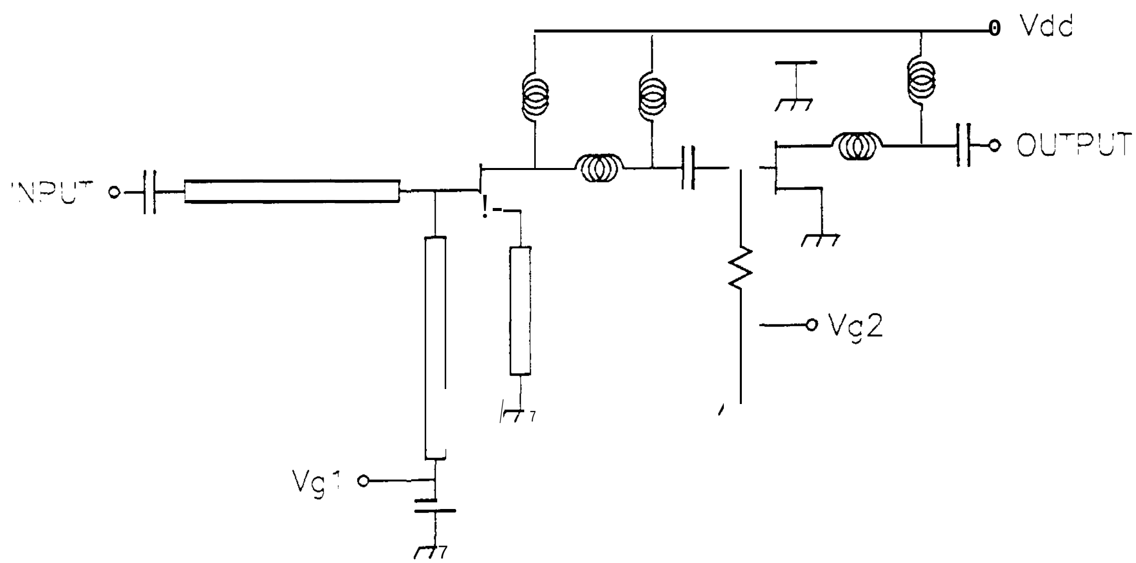
5) DIVIDE BY FOUR (Monolithic)

PARAMETER	GOAL	PREDICTED
INPUT FREQUENCY	8.353 - 8.553 GHz	8.15 - 8.8 GHz
INPUT POWER	0 dBm	0 dBm
OUTPUT POWER	0 dBm	5 dBm
HARMONIC OUTPUTS		-20 dBc
POWER CONSUMPTION		400 mW
CHIP SIZE		2.0 x 1.5 mm

6) DIVIDE BY FIVE (Monolithic)

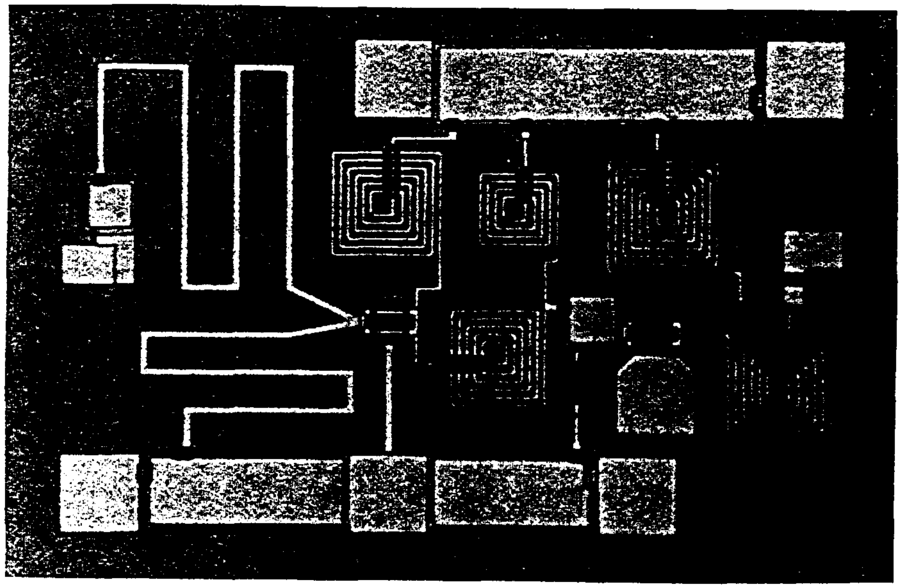
PARAMETER	GOAL	PREDICTED
INPUT FREQUENCY	2.088 - 2.138 GHz	2.05 - 2.15 GHz
INPUT POWER	0 dBm	0 dBm
OUTPUT POWER	0 dBm	5 dBm
HARMONIC OUTPUTS		-20 dBc
POWER CONSUMPTION		400 mW
CHIP SIZE		2.0 x 2.0 mm

SCHEMATIC DIAGRAM OF THE GaAs MMIC LNA / GAIN BLOCK

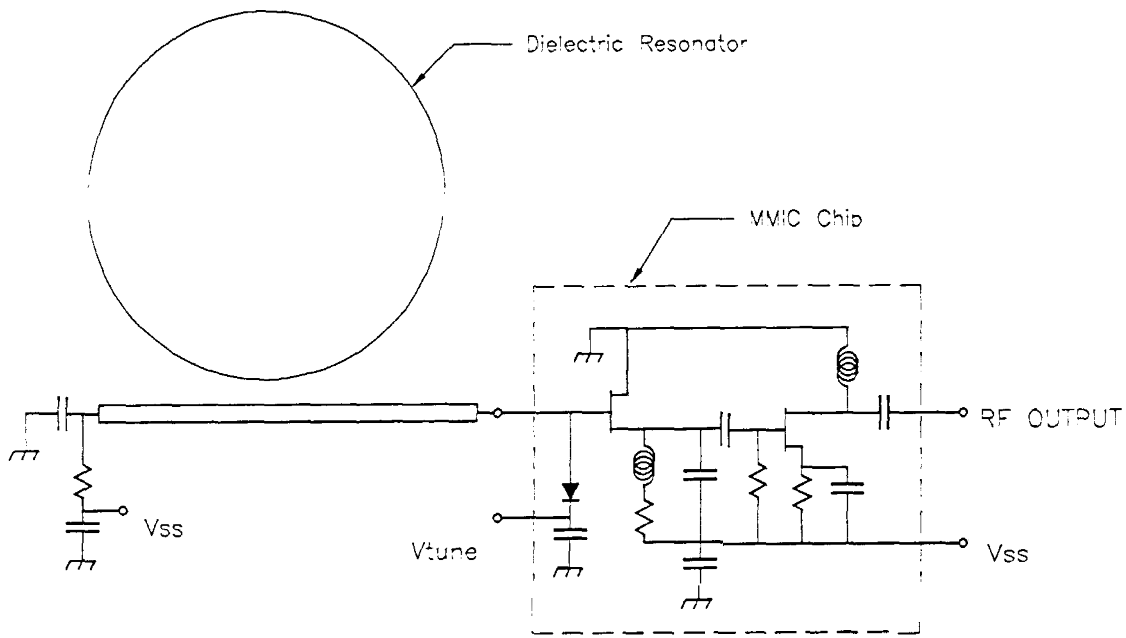


MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

PHOTOMICROGRAPH OF THE GaAs MMIC LNA / GAIN BLOCK CHIP

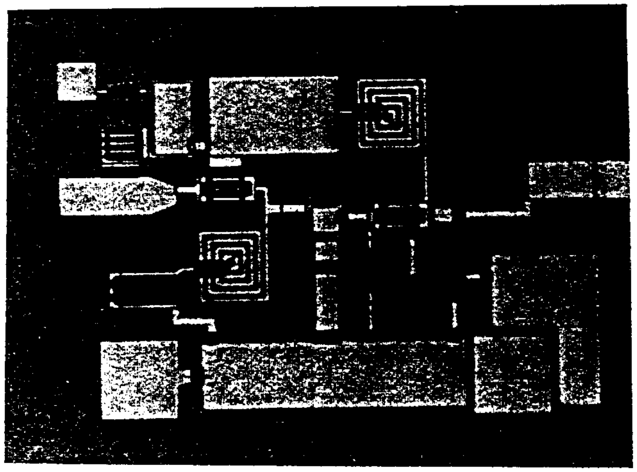


SCHEMATIC DIAGRAM OF THE GaAs MMIC VOLTAGE CONTROLLED DSO



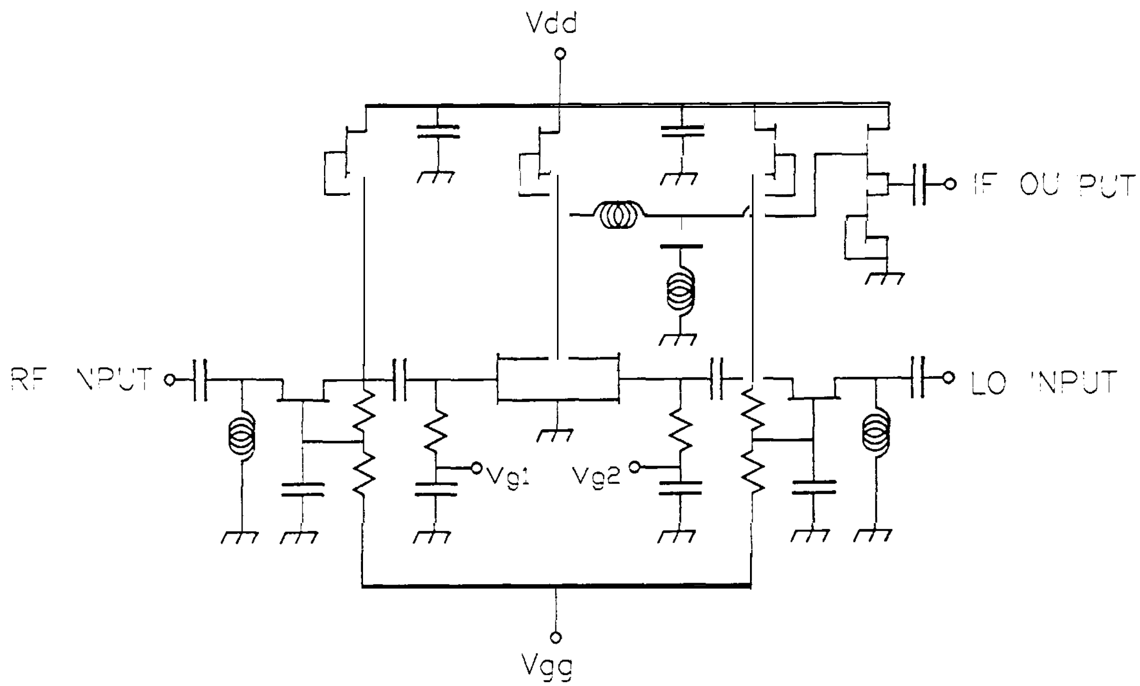
MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

PHOTOMICROGRAPH OF THE GaAs MMIC VOLTAGE CONTROLLED DSO CHIP



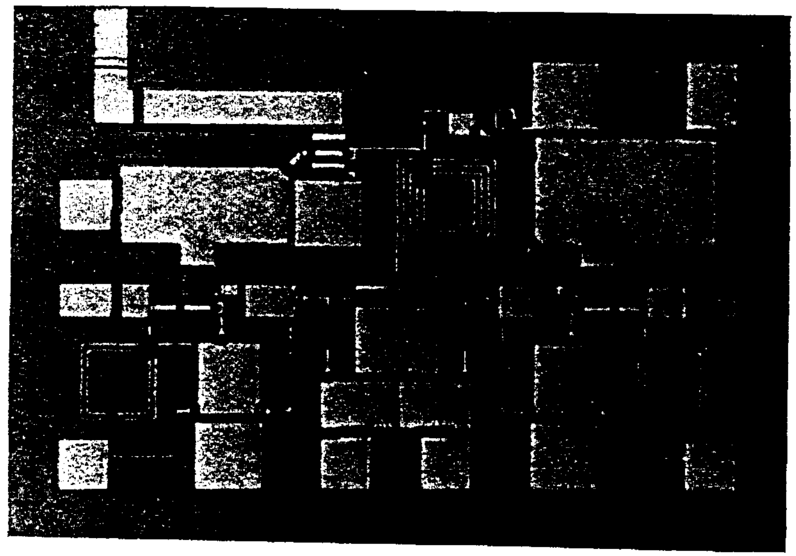
MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

SCHEMATIC DIAGRAM OF THE GaAs MMIC MIXER



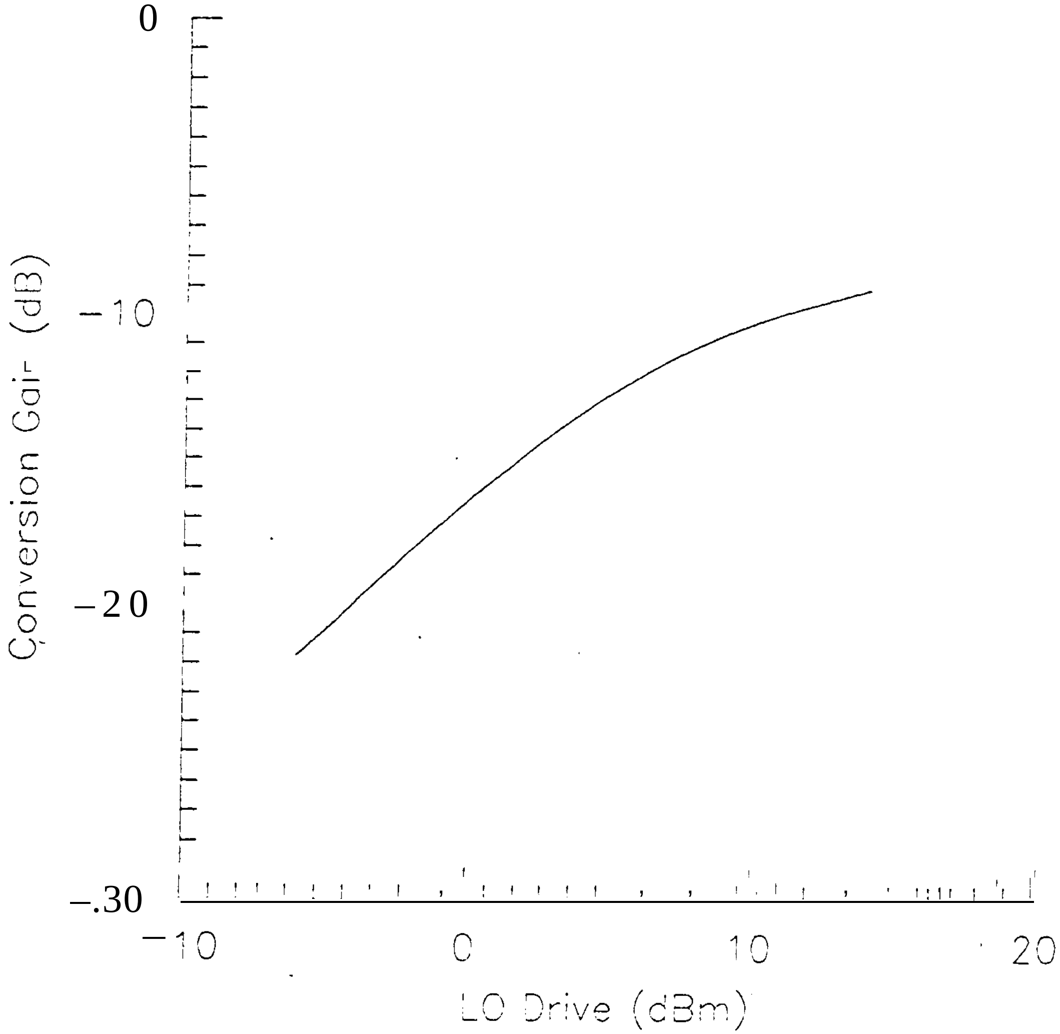
MONOLITHIC GaAs FRONT END FOR SPACE(XAFTT RANSPONDERA PPLICATIONS

PHOTOMICROGRAPH OF THE GaAs MMIC MIXER



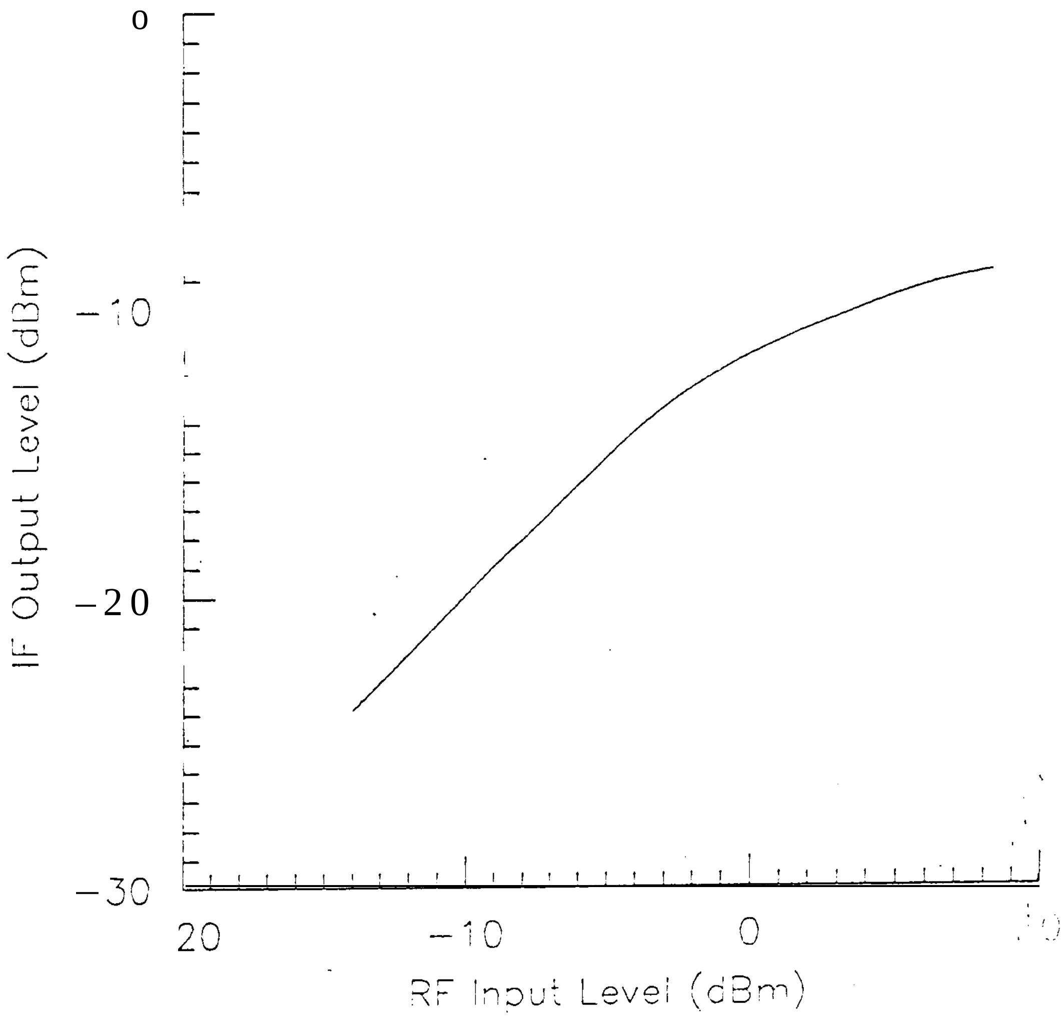
MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

CONVERSION LOSS VS LO DRIVE OF A FIRST-ITERATION MONOLITHIC MIXER



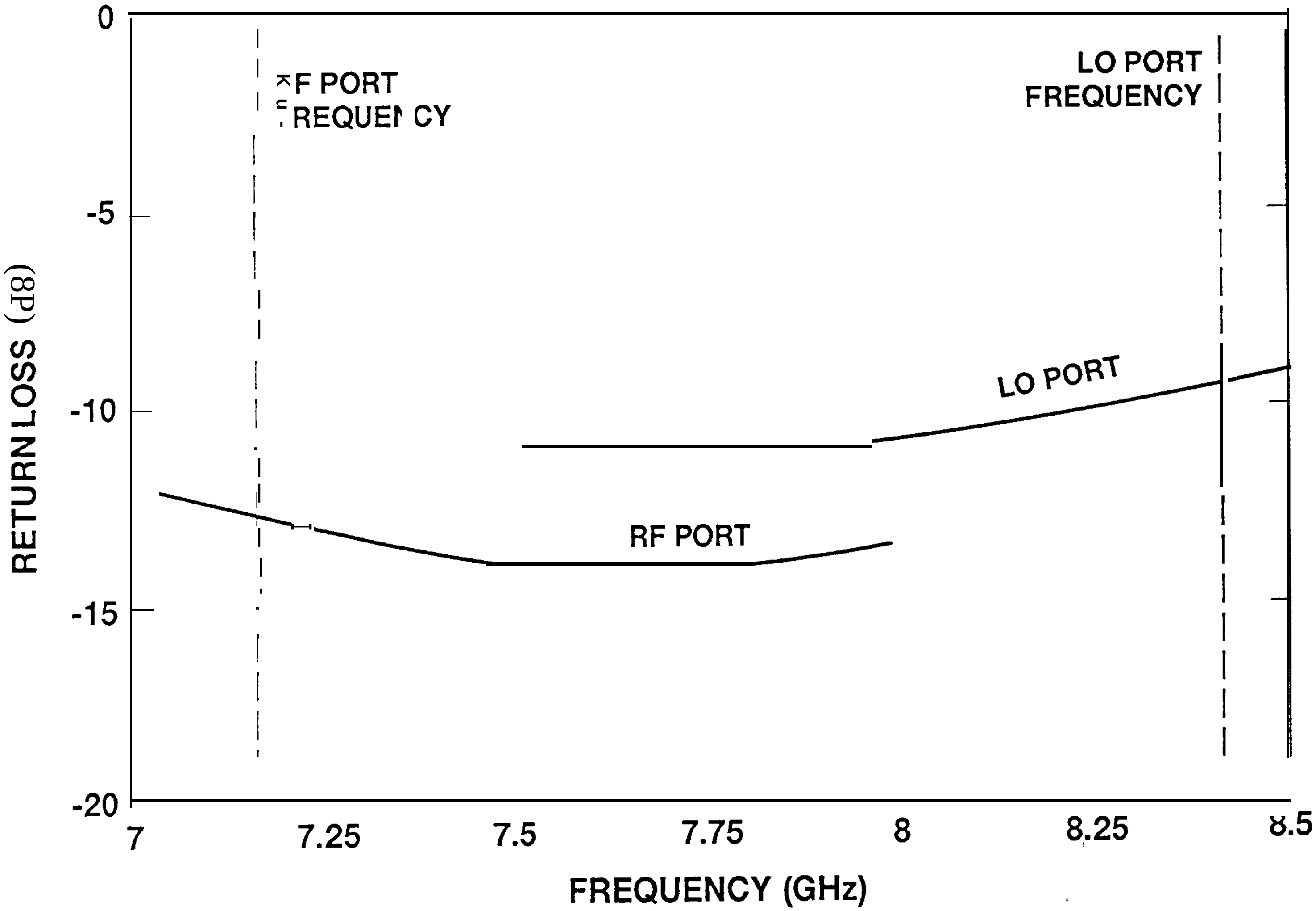
MONOLITHIC GAAS FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

~~IF OUTPUT LEVEL VS RF INPUT POWER OF A FIRST-ITERATION MONOLITHIC MIXER~~



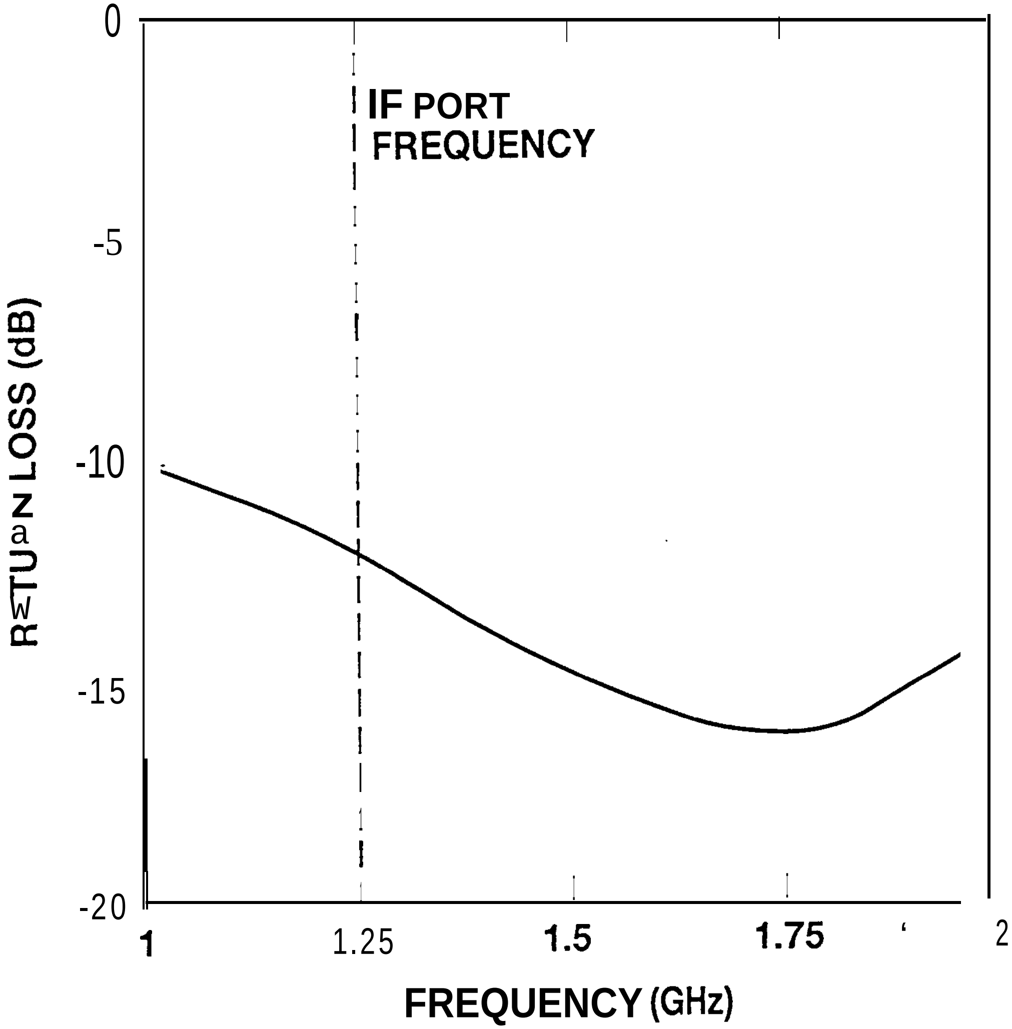
MONOLITHIC GaAs FRONT END FOR
SPACECRAFT TRANSPONDER APPLICATIONS

IMPEDANCE MATCH AT THE RF, AND LO PORTS OF THE MIXER

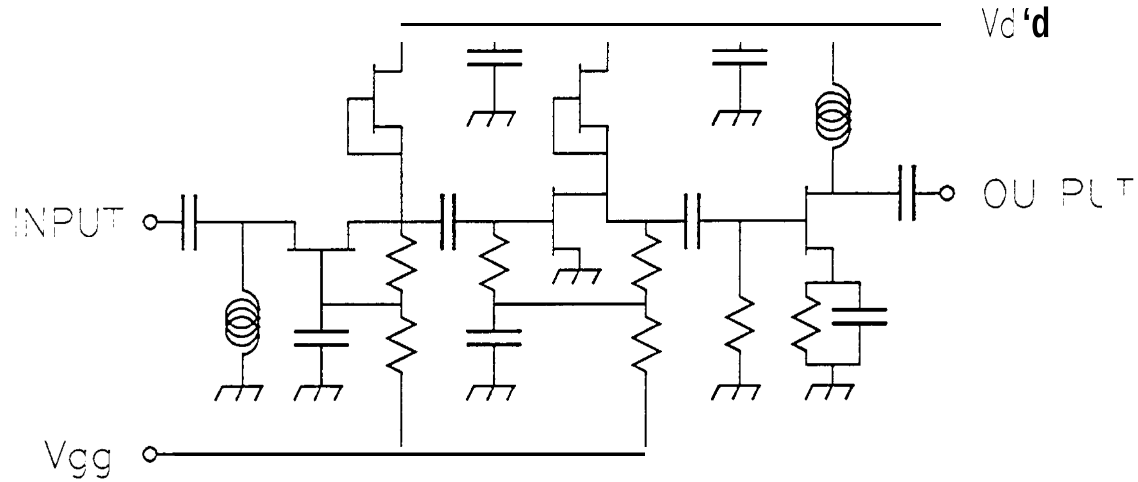


MONOLITHIC GaAs FRONT END FOR
SPACECRAFT TRANSPONDER APPLICATIONS

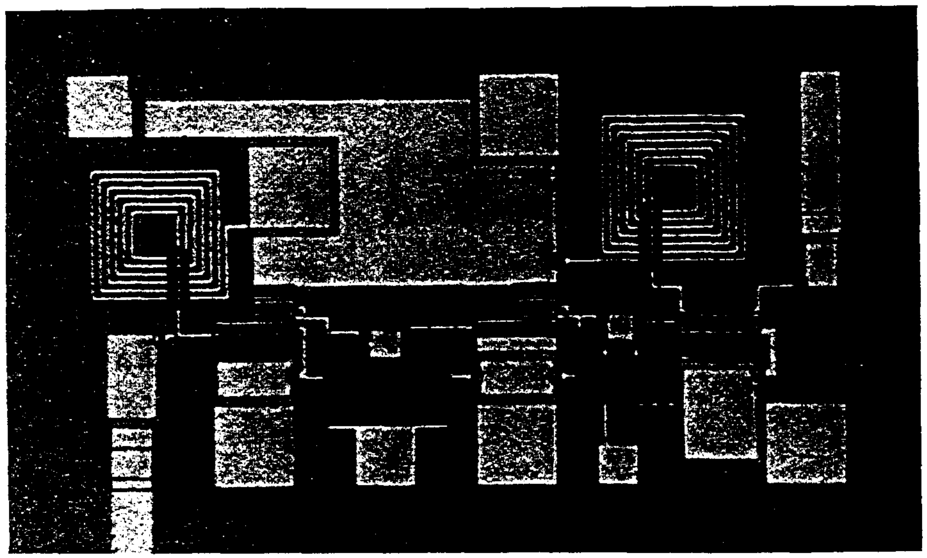
IMPEDANCE MATCH AT THE IF PORT OF THE MIXER



SCHEMATIC DIAGRAM OF THE GaAs MMIC IF AMPLIFIER

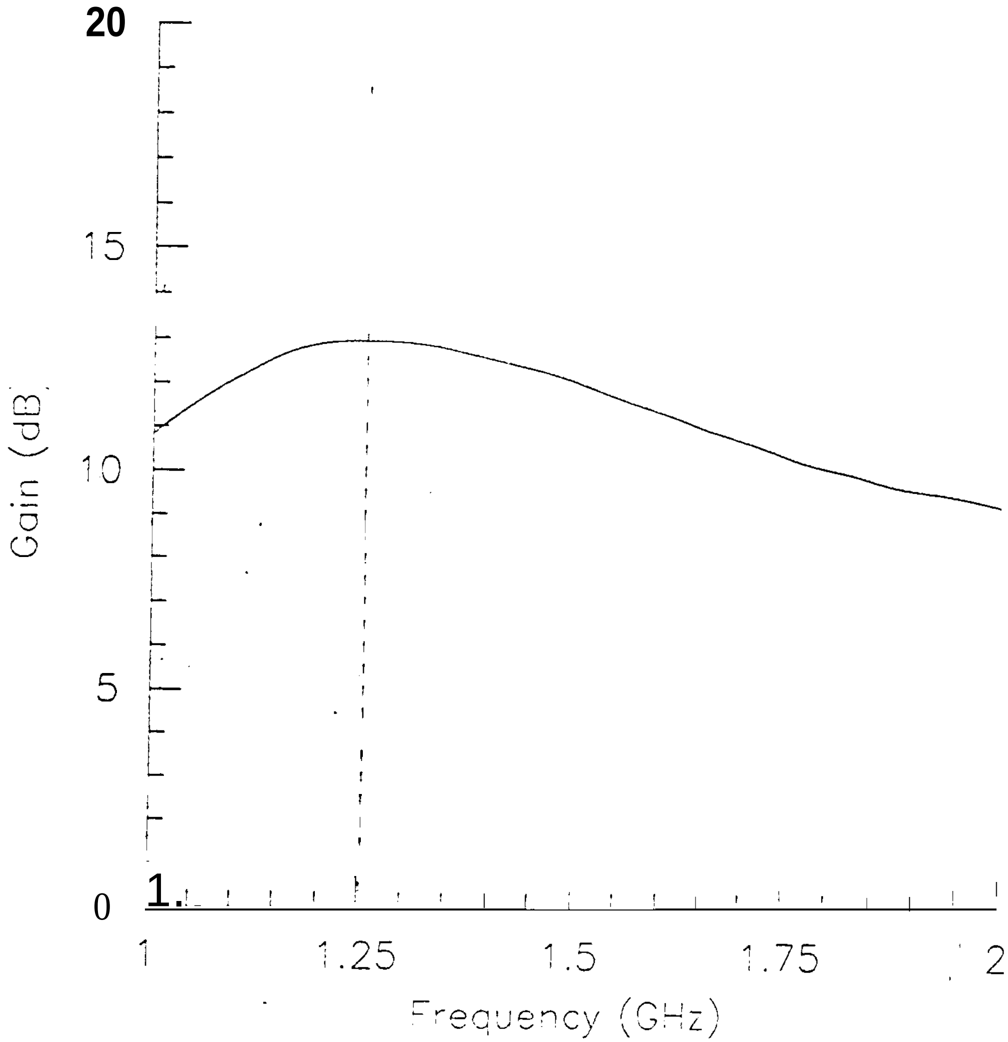


PHOTOMICROGRAPH OF THE GaAs MMIC IF AMPLIFIER

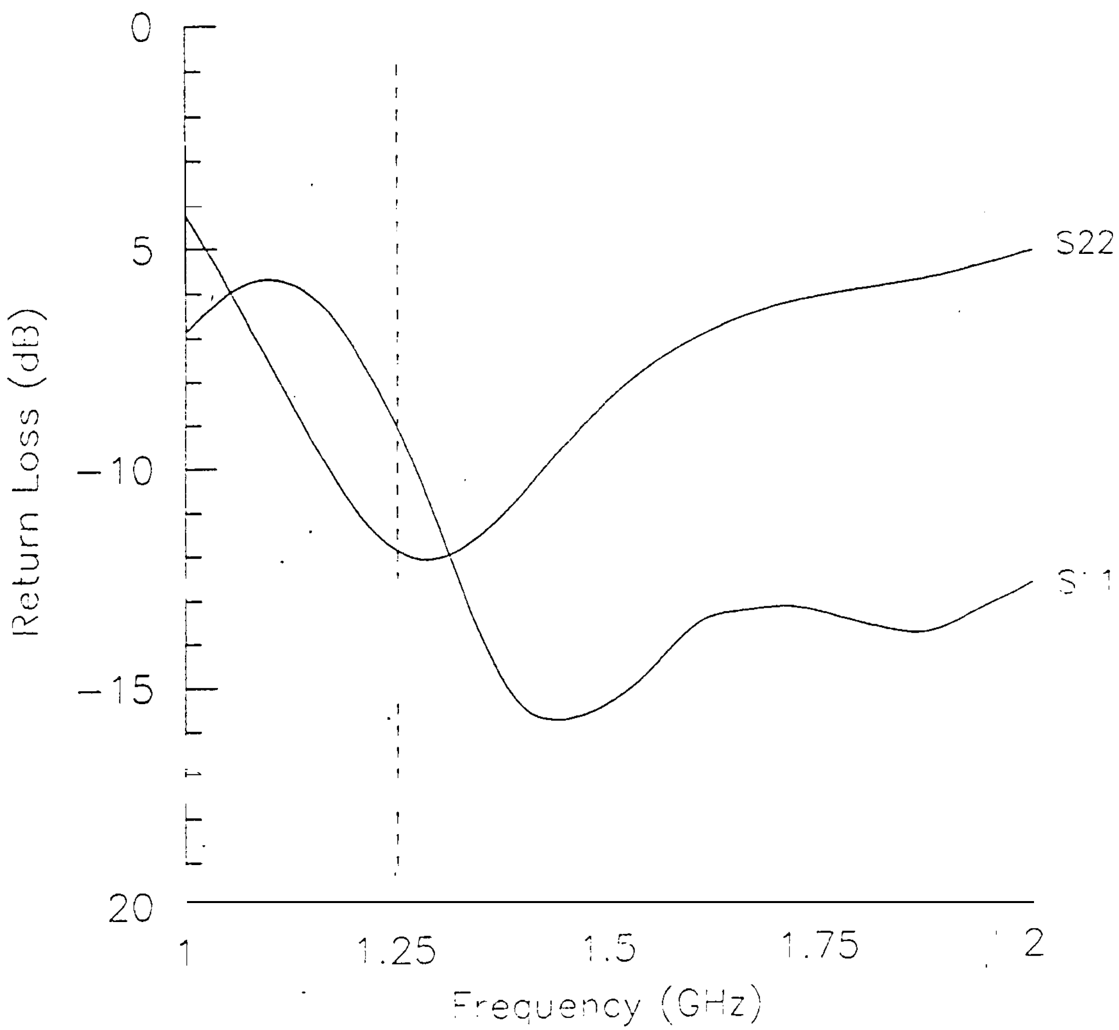


MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

MEASURED RESPONSE OF A FIRST-ITERATION MONOLITHIC IF AMPLIFIER



MEASURED INPUT & OUTPUT MATCH OF A FIRST-ITERATION MONOLITHIC IF AMPLIFIER



Approaches Capable of Coherent Microwave Frequency Division

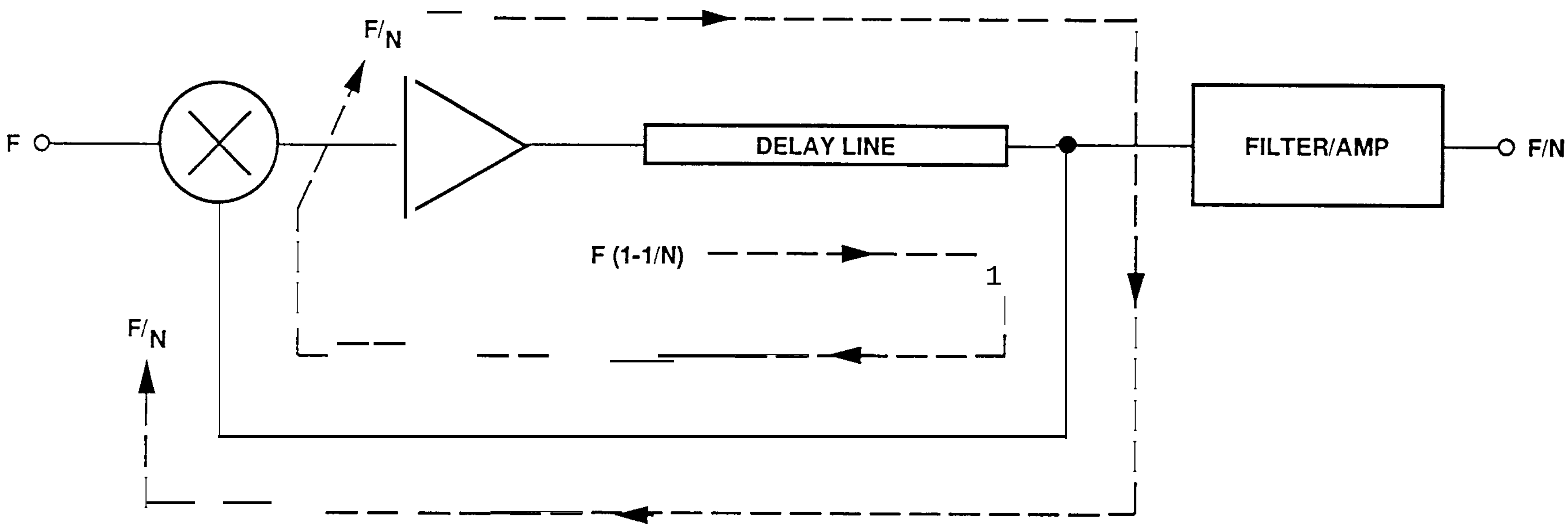
- o REGENERATIVE DIVIDER
  - Moderate N, Operation to 60 GHz
  - Large chip size
  - 0 to + 10 dBm input, Low conversion loss with amplifier
  - Low phase noise

- o BLOCKING OSCILLATOR
  - High N, Operation to 8 GHz
  - Medium chip size
  - 0 to + 10 dBm input, Conversion gain possible
  - Moderate phase noise

- o PARAMETRIC DIVIDER
  - Low N, Operation to 60 GHz
  - Small but not easily integrated
  - 0 to + 15 dBm input, High conversion loss
  - Moderate phase noise

MONOLITHIC GaAs FRONT END FOR
SPACECRAFT TRANSPONDER APPLICATIONS

REGENERATIVE DIVIDE-BY-N FREQUENCY DIVIDER



Regenerative Dividers

A Mixing divider is a nonlinear circuit which regeneratively supports the subharmonic oscillation in response to a driving input signal

o **Input signal mixes with noise to regeneratively produce Subharmonic frequency, $F_{out} = F/N$; and idler frequency, $F_1 = F(1 - 1/N)$**

0 **Requires gain and correct phase shift at both the desired output frequency and the idler frequency**
- Difficult at higher frequencies, and large N

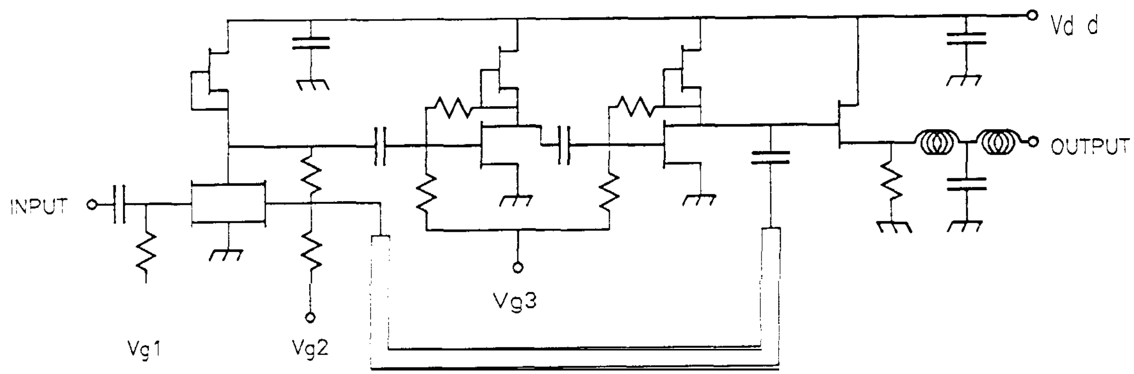
0 **Requires CW input signal**

0 ***N* should be preferably an even number**
Shorter delay line structure
Less spurious output signal

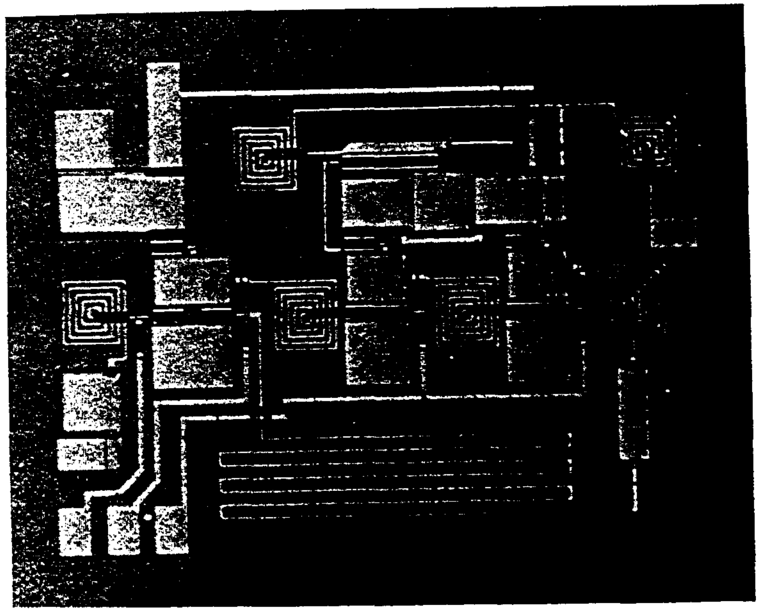
0 **Has been experimentally demonstrated at 12 GHz (N = 4, and 2), and at 16 GHz (N = 2) ,**

MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

SCHEMATIC DIAGRAM OF THE GaAs MMIC REGENERATIVE DIVIDE-BY-FOUR CIRCUIT

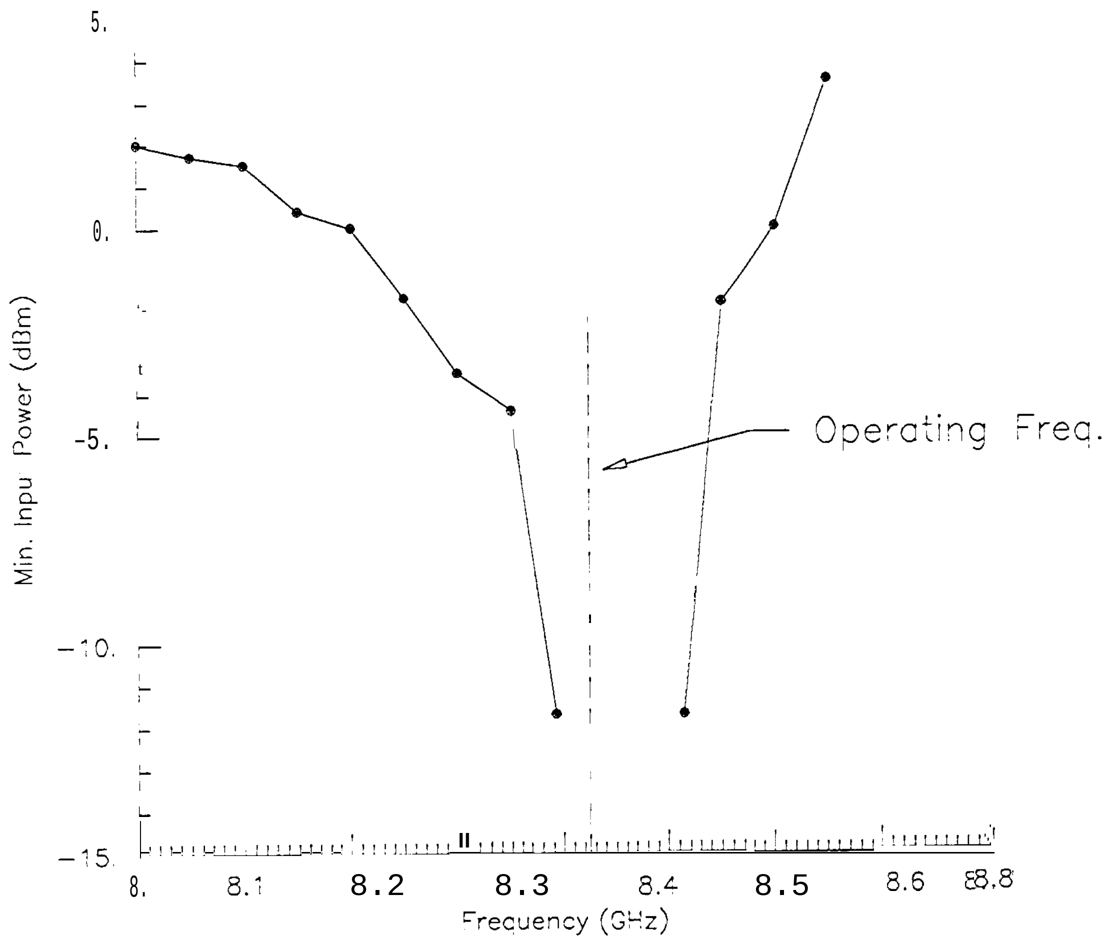


PHOTOMICROGRAPH OF THE GaAs MMIC REGENERATIVE DIVIDE-BY-FOUR CIRCUIT

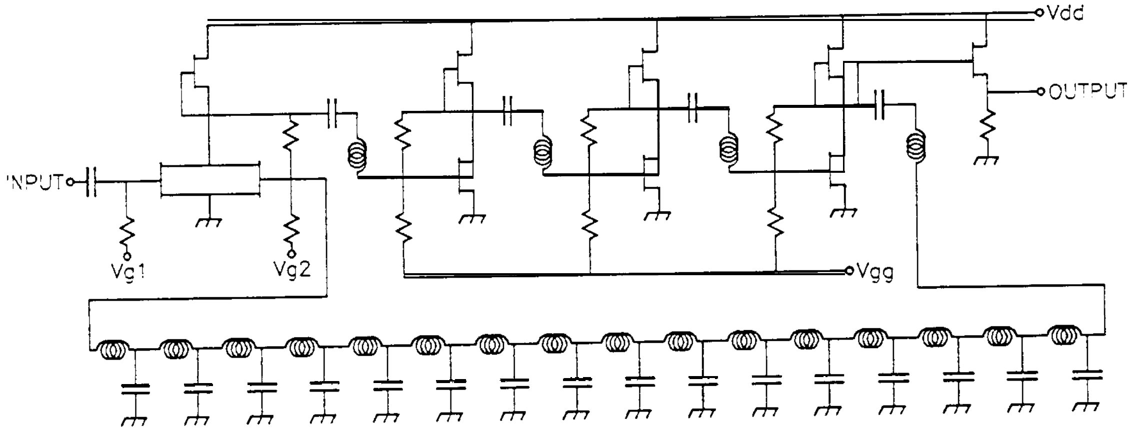


MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

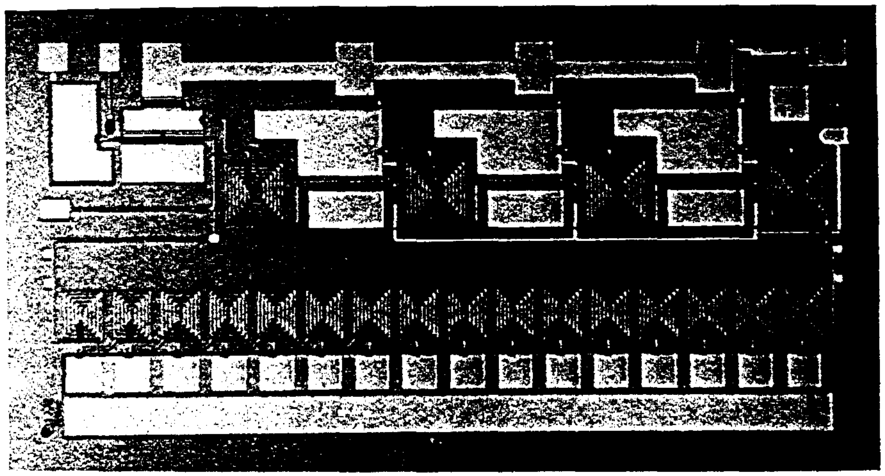
MEASURED INPUT SENSITIVITY OF THE DIVIDE BY FOUR MMIC



~~SCHEMATIC DIAGRAM OF THE GaAs MMIC REGENERATIVE DIVIDE-BY-FIVE CIRCUIT~~

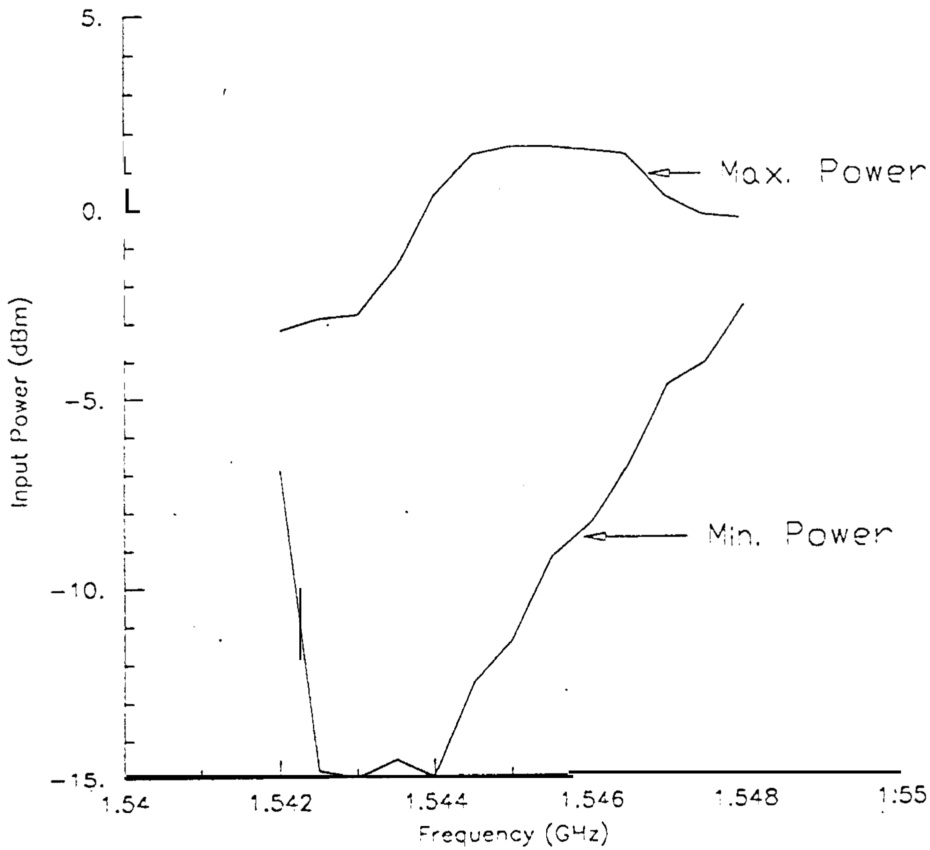


PHOTOMICROGRAPH OF THE GaAs MMIC REGENERATIVE DIVIDE-BY-FIVE CIRCUIT



MONOLITHIC GaAs FRONT END FOR SPACECRAFT TRANSPONDER APPLICATIONS

~~MEASURED INPUT SENSITIVITY OF THE DIVIDE BY FIVE~~ MMIC



SUMMARY

- o Seven different MMIC circuits on the same GaAs substrate have been designed and fabricated for the transponder receiver front end applications

- o Judicious design, ion implanted process, and refractory metal MESFETS are used to increase the yield, and reliability of the receiver front end

- o First iteration circuits function close to expectations
  - VCO, mixer, and divide-by-four circuits meet the design requirements
  - RF amplifier, IF amplifier, and divide-by-five circuit with an alternative phase compensation circuit will be redesigned to meet the design requirements

- o A second design/fabrication iteration is planed to complete the MMIC receiver front end breadboard

- o Applicable to high reliability, small size, and light weight communication systems for micro spacecraft applications